h. Part III-5-13 provides some detailed guidance on the specific coastal engineering and management issues associated with cohesive shores. The success of engineering and management techniques on cohesive shores is dependent on a recognition of the fundamental differences between sandy and cohesive shore processes. Engineering techniques that may have been successful on the more familiar sandy shores, may be unsuitable or inappropriate along cohesive shores.

III-5-5. Geomorphology of Consolidated Shores

This section provides a review of the geomorphology of cohesive shores and the relationship between the land forms and the erosion processes discussed in the previous sections. The discussion is subdivided under two headings: "Controlling Factors" and "Profile Types." This section focuses on the geomorphology of consolidated cohesive sediment shores. For more detail on erosion processes along rocky coasts, refer to Sunamura (1992).

a. Controlling factors. The primary controlling factors discussed in the following paragraphs influence the geomorphology of cohesive shores:

(1) Lag deposits.

(a) Some consolidated cohesive sediment units have cobbles or boulders within their composition. For example, along the Great Lakes, glacial till may be either fine-grained or stony (i.e., containing gravel and cobbles). During the evolution of stony till shores, the cobbles and boulders that are left behind after the removal of the finer clay, silt, and sand build up to form a protective armor for the underlying till. In these cases, an erosion-resistant nearshore shelf will usually have formed. The depth of the shelf at any location is such that the lag deposit remains immobile, and therefore the depth is determined by the local wave climate and the grain size of the lag deposit. Generally, for the Great Lakes, the depth of this shelf is approximately 2 m below low water datum. Along sea and ocean coasts with large tidal ranges and longer waves, lag deposits may occur at much greater depths (e.g., lag deposits over clay have been found in water depths of 10 m below datum along the North Sea coast of England). The shelf creates what has been referred to as a convex profile, in contrast to the concave profile associated with situations where lags are not present.

(b) The armored shelf acts to dissipate wave energy, and therefore reduce or even prevent bluff erosion. Boyd (1992) gives several examples where a bluff is protected from erosion by a nearshore shelf and notes that the reduced wave energy may also allow a stable beach to exist at the shore, providing additional protection to the bluff toe. Natural headlands along an eroding cohesive shoreline often owe their existence to the presence of a lag-protected nearshore shelf.

(c) An example of a site where a lag deposit has resulted in an erosion-resistant foreshore and a stable shoreline is located near the town of Goderich on the Canadian shore of Lake Huron. A nearshore profile for this site is shown in Figure III-5-10. The cobble-protected shelf has a depth of 1.75 m and is about 200 m wide. The stratigraphy at the site consists of a stony till unit below the average lake level and a fine-grained till unit above the average lake level. At nearby sites where the fine-grained till unit dips below the average lake level to depths of greater than 2 m, and the nearshore shelf is no longer present, the bluff recession rates range from 0.3 m/year to over 1 m/year.

(2) Different stratigraphic units.

(a) Along most cohesive shores, 3-D variations in contact surfaces between stratigraphic units are common. This results from the complex geomorphologic conditions that formed the underlying geology, which, depending on the location, may include some combination of: glacial, lacustrine, estuarine, or fluvial

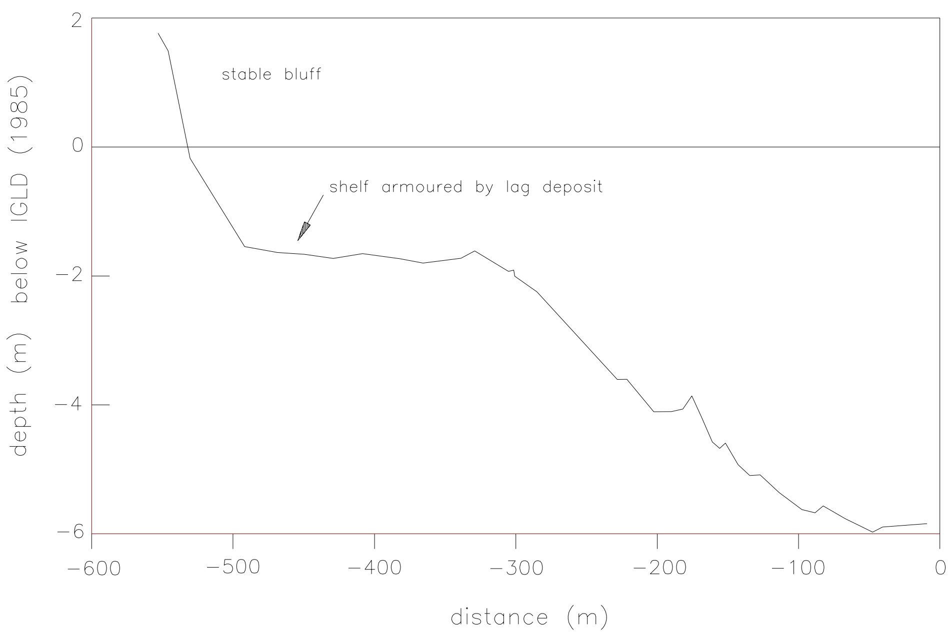

Figure III-5-10. A convex consolidated cohesive profile with a shelf protected by lag deposits located near Goderich, Ontario, on Lake Huron

processes. Therefore, as the shore erodes in time, the recession rates can change, as either more or less erosion resistant, units are encountered further inland. One example of the influence of erosion resistance is East Point located along the Scarborough Bluffs east of Toronto on Lake Ontario. The plan and stratigraphy cross section of this feature are shown in Figure III-5-11. Clearly, East Point is an expression of the more erosion-resistant Leaside (or northern) till unit, which dips below the average lake level at this location. Leaside till is relatively hard and includes boulder pavements (Boyce, Eyles, and Pugin 1995). Along the neighboring shore, the less erosion-resistant Scarborough clay unit exists below the lake level.

(b) Recognition of the variation in erosion resistance of different till units resulted in an unlikely finding during the investigation of the influence of a harbor structure at Port Burwell on downdrift erosion along the north central shore of Lake Erie (Figure III-5-12). A long harbor jetty here intercepts almost all of the sand moving along the shore from west to east, therefore depriving the downdrift shore of sediment. On a sandy shore, this would be a clear case of downdrift erosion due to sediment supply starvation. However, the investigation described by Philpott (1984) revealed that cohesive shores along the north central shore of Lake Erie seldom have (and probably never had) enough sand to halt the downcutting of the underlying till. Updrift of the harbor, the trapping of large quantities of sand eventually halted the nearshore profile downcutting, and the bluff position was stabilized. However, this still did not fully explain why recession rates updrift of the harbor fillet beach were generally lower (about 1 m/year) than those on the downdrift shoreline to the east (in the range of 2 to 4 m/year).

(c) Figure III-5-12 also describes the bluff face stratigraphy at Port Burwell. There is a change in the subaqueous stratigraphic unit at the harbor mouth, where Port Stanley till exists below the lake level on the updrift side and Waterlain till forms the nearshore profile on the downdrift side. Based on a comprehensive investigation, including laboratory testing of the erodibility of the different till units, it was concluded that Waterlain till was less erosion-resistant than the Port Stanley till. It is not coincidental that the change in till

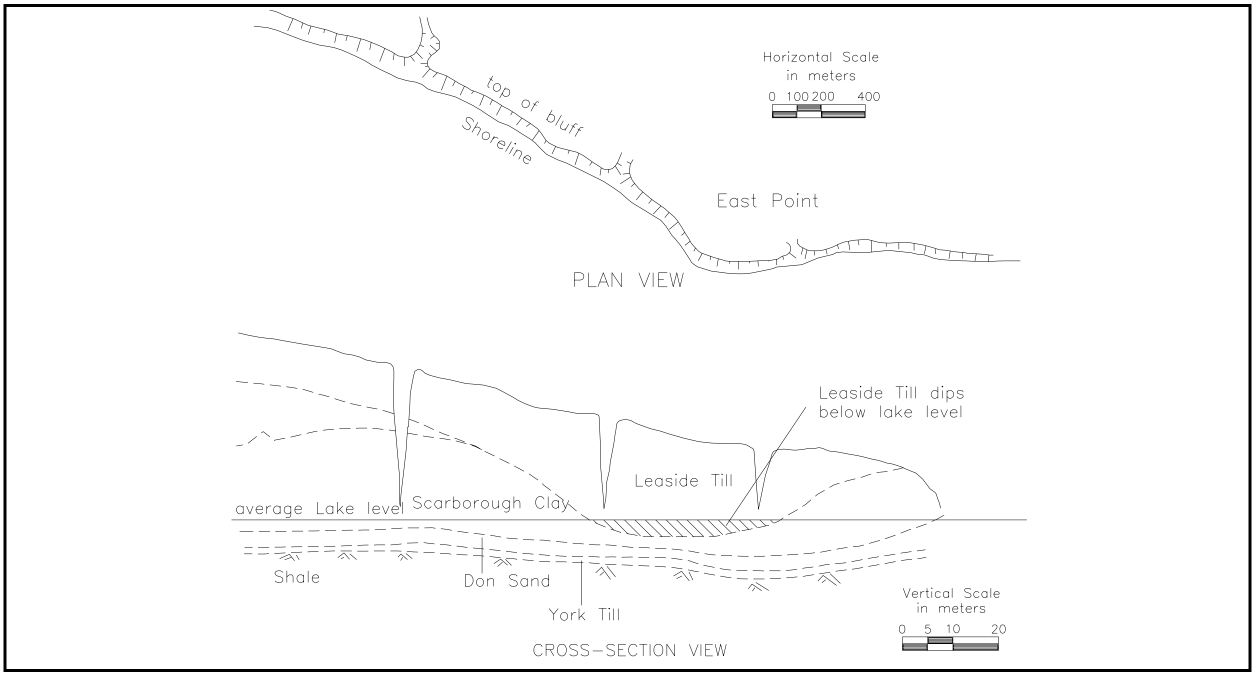

Figure III-5-11. Plan and cross section of East Point along the Scarborough Bluffs (located east of Toronto on Lake Ontario) showing the influence of the erosion-resistant leaside (or northern) till on the local geomorphology

occurred at the harbor mouth, as often creeks or rivers follow the interface between different stratigraphic units.

(d) Riggs, Cleary, and Snyder (1995) provide several examples of both headlands (local areas of slowly retreating or stable shoreline) and local sections of rapidly retreating shoreline, that are a direct result of variability in the erosion resistance of different stratigraphic units that make up the shoreface. They found that headlands result from the presence in the nearshore of more erosion-resistant Pleistocene or older sediments. In contrast, rapidly retreating sections of shore consisted of sand-poor, valley-fill sediment or compact peats and clays deposited in modern estuarine environments.

(3) Quantity and mobility of sand cover.

(a) In natural situations, a protective sand cover can build up over an erodible substrate and protect it from further erosion. Investigations of Great Lakes sites have shown that approximately 200 m^3/m of sand cover (measured from the top of the beach out to the 4-m contour) is required to halt the downcutting process (Nairn 1992). However, even half as much as this quantity can afford at least some protection to the underlying cohesive substratum.

(b) Another important factor is the volatility or mobility of sand cover. If the overlying noncohesive bed forms are rapidly and frequently changing position, the underlying cohesive substratum will be exposed to erosive situations more frequently. Nairn and Parson (1995) have indicated that on the Great Lakes, the shift of bar position in response to changing lake levels has an important influence on the exposure of the underlying till (in the troughs between the bars) to erosion. On an eroding cohesive bluff shore along the North Sea coast of England, Pringle (1985) identified alongshore migrating areas of reduced beach cover and exposed glacial till called 'Ords.' These Ords have an important role in exposing the underlying glacial till to erosion. Figure III-5-13 shows an Ord on the Holderness coast at low tide with glacial till exposed (partly

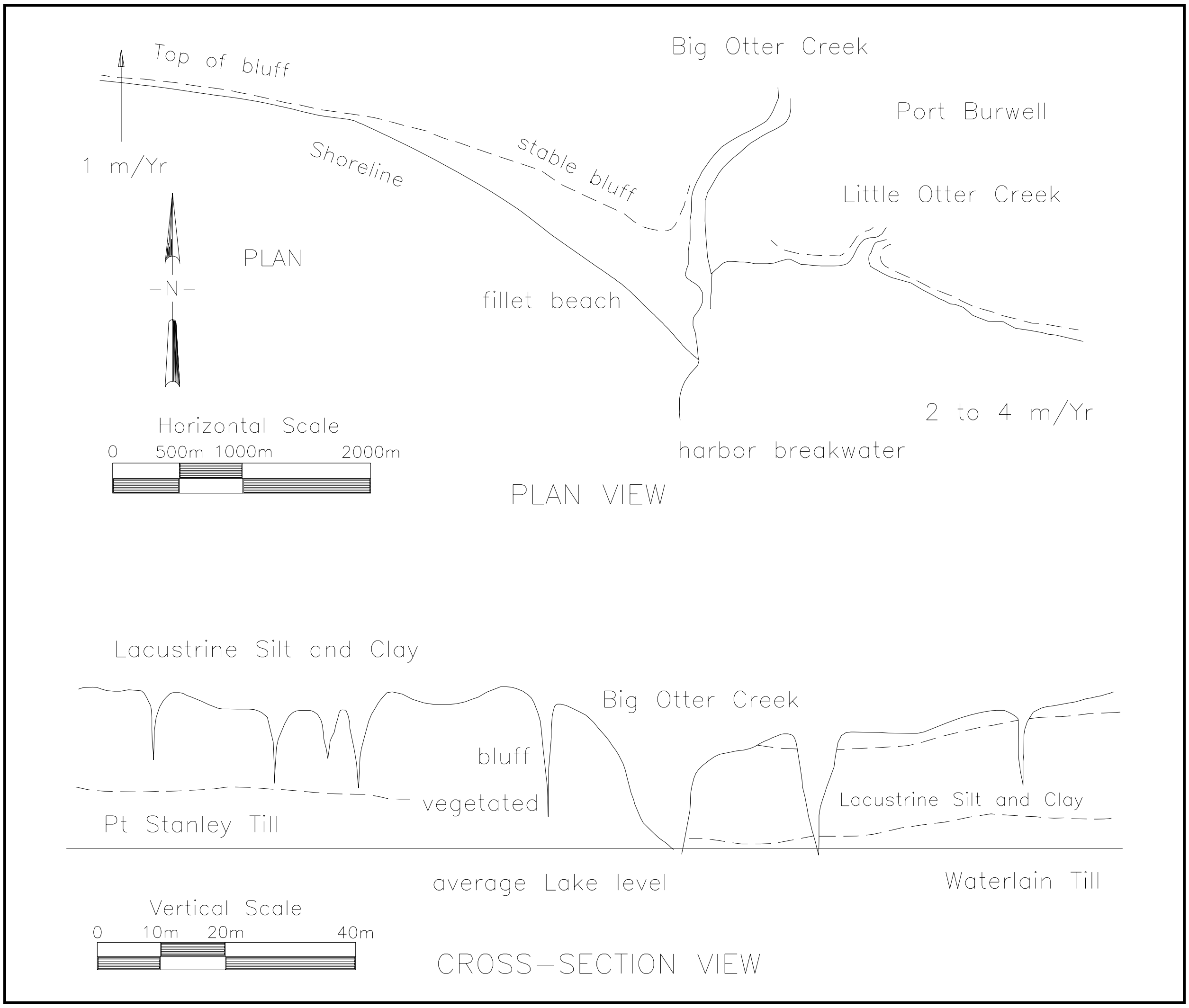

Figure III-5-12. Plan and cross section of the Port Burwell area on the north central shore of Lake Erie showing the influence of a fillet beach and stratigraphy changes on the geomorphology of a cohesive shore

covered with cobbles) between the upper coarse sand beach and a bar consisting of finer sand. The closeup photo of the Ord (Figure III-5-14) shows erosion of the exposed till around a 10-cm-high pedestal protected by a rock cap. Pringle (1985) found that the migration rate for these features was approximately 500 m/year, which is similar to the rate of migration for large sand waves or rhythmic features along Long Island, NY (Thevenot and Kraus 1995). An Ord could be defined as the area between two migrating sand waves. In summary, both cross-shore and alongshore variations in sand cover thickness resulting from migration of bars and sand waves or Ords, respectively, have an important influence on the rate of cohesive sediment erosion in the nearshore zone.

(c) Deposition of large quantities of sand over a cohesive substrate can occur at a change in shoreline orientation where the potential alongshore sediment transport rate rapidly decreases, or at a natural obstruction to alongshore transport, such as at a rock headland. Other instances where sand may eventually build up to protect a profile include sites where the alongshore transport of sediment is intercepted at a harbor jetty. The Port Burwell fillet beach shown in Figure III-5-6, as discussed above, protects the nearshore cohesive substratum and has stopped the bluff recession behind the fillet beach.

Figure III-5-13. Bluff erosion along the Holderness coast of the North Sea. The underlying cohesive profile is exposed at low tide in a trough (referred to as an "Ord") between the upper beach and first bar

Figure III-5-14. Close-up of the exposed cohesive profile on the Holderness coast (Figure III-5-13). A rock-capped pedestal of cohesive sediment, about 10 cm in height, has developed through erosion of the adjacent seabed